ISSN 0040-6015, Thermal Engineering, 2009, Vol. 56, No. 9, pp. 747–752. © Pleiades Publishing, Inc., 2009.
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Retrofitting of T-100/110-12.8 Cogeneration Steam Turbines

A. E. Valamin, Yu. A. Sakhnin, V. B. Novoselov, and A. A. Ivanovskii

ZAO Ural Turbine Works, ul. Frontovykh Brigad 18, Yekaterinburg, 620040 Russia

Abstract—Problems relating to replacement and retrofitting of steam turbines that have worked through their service life are considered, and methods for extending their service life are discussed. Concrete activities carried out at Ural Turbine Works in the course of renovating and retrofitting T-100/110-12.8 turbines are presented.

DOI: 10.1134/S0040601509090067

The problem of replacing old and outdated steam turbines is as old as the industry constructing steam turbines. In the former Soviet Union, this problem was solved as a state-level program on the basis of the decree “About Setting Up Manufacture of Assemblies and Parts for Heat-Generating and Mechanical Equipment of Power Stations to Replace the Ones That Have Worked Through Their Service Life and Guaranteeing Their Manufacture in the Period from 1981 to 1990” adopted by the USSR Council of Ministers in July of 1980. It was expected that the combined capacity of equipment that have worked through their service life would reach 60 GW by 1990. This problem included several tasks that had to be solved in parallel.

(i) Dismantling of the obsolete and physically worn turbines. It was planned that turbines with a total capacity of 3.926 GW had to be dismantled in the period from 1981 to 1985 and 4.879 GW in the period from 1986 to 1990 (a total of 68 turbines). This task was accomplished.

(ii) Determination of limiting service life. In 1980, the limiting service life of equipment operating at 9 MPa was established equal to 220000 h; that of equipment operating at 12.8 MPa, 170000 h; and 150000 h for nozzle vanes and high-pressure diaphragms. As is well known, these indicators have at present been established as equal to 270000 and 220000 h, respectively.

(iii) Reequipment of turbines with new stop valves, nozzle vanes, and high-pressure diaphragms. In pursuance of this task, Turbine Engine Works re-equipped 11 turbines with a capacity of 50–55 MW, 16 turbines with a capacity of 25 MW, and around 30 turbines with a capacity of 100 MW.

(iv) Comprehensive replacement of high-pressure shells with rotors, nozzle vanes, control and stop valves, and seals. By 1990, PO Turbine Engine Works (UTMZ) had accomplished 40% of this task by replacing the high-pressure parts in the following types of turbines: VPT-25-3 (nine units), PT-50-12.8 (six units), and T-50/55-12.8 and T-100/120-12.8 (six units). In addition, two T-50/55-12.8 turbines and six T-100/120-12.8 turbines were comprehensively replaced after 1990.

Work on implementing the state program was stopped in 1990–1991, and the problem itself has now become still more acute: approximately 50% of the 2000 turbines that are in operation have been in operation for more than the increased service life. As applied to the standard list of turbines manufactured at the UTMZ (presently, Ural Turbine Works), all VPT-25-3, VPT-25-4, and PR-25-90/10/0.9 turbines; all T-50/55-12.8 and PT-50/60-12.8/7; almost half of T-100/120-12.8 (-1, -2, and -3) turbines; all R-38(40)-12.8-3 turbines; half of R-100-12.7/5 turbines, and three T-250/300-23.5 turbines have worked out their fleet service life.

Clearly, even if the production facilities of UTZ were to be loaded to full capacity, it would take around 30 years for the enterprise to replace the turbines that have worked through their service life; the same period of time would be required to replace the second part of turbines aged for these 30 years.

A similar state of things we have with the turbines produced by Leningrad Metal Works, PO Turboatom, and KTZ. Pointwise commissioning of new steam turbines as part of combined-cycle plants of different power capacities will not rectify the situation.

The following natural conclusion suggests itself: renovation and simultaneous retrofitting of turbines aimed at increasing the capacity and improving the economic efficiency of each turbine unit is the shortest and a comparatively cheap way in which the operability of the turbine fleet can be restored. This approach is naturally supplemented by complete replacement of outdated turbines by new-generation turbines, by installing combined-cycle plants, and by constructing two-shaft installations through the use of bottom turbines [1].

Simpler methods for extending the operation of old turbines may of course be used, namely,

(i) according to the actual state of the metal of the stop valve and high-pressure cylinder (HPC). As a rule, such an extension is issued for 20000–30000 h of operation; and

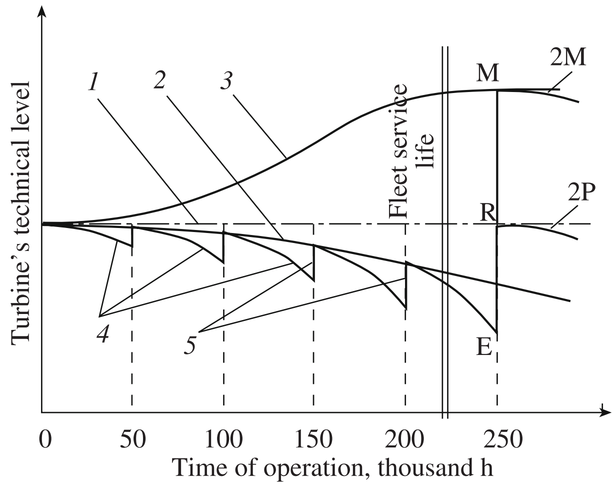

Fig. 1. Change in the technical level of a turbine in the course of its operation. (*1*) Technical level of a turbine at the beginning of its operation (it corresponds to the manufacturer's technical specifications), (*2*) degrading technical level in the course of turbine operation (degradation of the parameters characterizing heat resistance and creep, wear, accumulation of damages, and the like), (*3*) technical level of new turbines after their commissioning, (*4*) degradation of technical level in the period between repairs, (*5*) restoration of technical level in the course of overhaul; GR is turbine renovation (e.g., in the scope determined in the decree of the Soviet Council of Ministers adopted in 1980), GRM is renovation and modernization of a turbine as a proposed way, and 2R and 2M are the changes in the technical level after GR or GRM similar to (*2*).

(ii) reducing the initial steam parameters, primarily its temperature, in order to bring the metal below the threshold after which creep intensely manifests itself. Such a measure unavoidably results in degraded capacity and economic efficiency and can be used as a means of preserving the turbine in expectation of its subsequent renovation and retrofitting.

This approach can be explained by graphically depicting the "biography" of a turbine (as a generalized pattern) (Fig. 1).

Below, the proposed renovation and simultaneous retrofitting of a turbine are considered taking the T-100/120-12.8 (T-110/120-12.8) turbine of UTZ as an example, which is the most popular one in Russian cogeneration stations.

The full scope of renovation and retrofitting includes the following work.

(1) *Comprehensive replacement of the HPC, including the flow path and valves.* The cylinder body is manufactured again so that it becomes possible to install either a two- or single-bucket control stage. The new cylinder has been designed so that considerably lower temperature stresses occur in it, especially in the control stage's chamber.

The HPC body of the turbine being replaced can also be used after subjecting it to restorative thermal treatment (which guarantees a further service life of no less than 200000 h) and introducing design modifications due to which a lower level of temperature stresses is obtained.

The use of a new flow path opens the possibility to increase the flowrate of live steam either to 495–510 t/h (which corresponds to a power output of 116–125 MW) or to 505–530 t/h (a power output of 118–130 MW). The heat loads will be equal to 770–807 and 786–823 GJ/h, respectively.

The flanges and studs are heated by steam extracted behind valve No. 1 through a deepened bead in the flange of the horizontal joint. A new current pick-off system with monitoring the grounding current is installed.

The flow path's internal efficiency is increased by 3.5–6.0% owing to the fact that the radial seals above the shrouds are replaced by axial ones (+2.5%) or by cellular ones (+3.5%) and that cellular sealing surfaces are arranged in the end and diaphragm seals (+1%). The use of a single-bucket control stage allows the economic efficiency to be increased by another 2.5–3.0%.

(2) *Comprehensive replacement of the intermediate-pressure (IP) flow path.* A new IP rotor furnished with a strengthened disk and rotor blades of the 15th, 20th, and 22nd stages and welded diaphragms of all IP stages are installed. All fitted-on disks, which are made of high-ductility steel, are secured by means of end-face keys. If necessary, the surfaces of fitted-on disks are subjected to fretting and the working blades are strengthened using the ionic implantation method.

It is recommended that new IP yokes be installed in order to decrease the volumes of erection works and shorten the time taken to carry out retrofitting work. The end seals, as well as the diaphragm seals of stages up to the 17th stage inclusively, are furnished with cellular sealing surfaces. The overshroud seals of stages up to the 17th one, inclusively, are either of the axial–radial or the cellular type. The resulting increase in the internal efficiency of the IP flow path will be no less than 2%.

(3) *Comprehensive retrofitting of the high-pressure part's stop valve and control valves.* A new valve is placed in the new shell (or in the old one that has been subjected to restorative thermal treatment), the design of which is such that the balancing valve does not hang in the intermediate position; therefore, cases in which the stop valve is not fully closed during scheduled shutdowns and emergency tripping operations are excluded.

New control valves furnished with perforated balls are installed. The valve seats have a convergent inlet part. The valve rod is furnished with a strengthened suspension.

The cam-type distribution device is installed on a new stiffer frame; the sector and gear are strengthened, and the cam shaft support bearings with higher static load capacity are installed.

Roller bearings are placed in the assemblies through which the sector is connected to the cam frame. The sector is made with two eyes through which it is connected to the high-pressure part's servomotor, a solution that allows a longer service life of the toothed pair to be obtained.

(4) *Comprehensive replacement of high- and intermediate-pressure steam admission pipes.*

(5) *Comprehensive replacement of semiflexible couplings connecting the intermediate-pressure rotor to the low-pressure rotor and the low-pressure rotor to the generator rotor by rigid ones.*

(6) *Comprehensive retrofitting of the system for draining the intermediate- and low-pressure cylinders (IPC and LPC), including means for removing process moisture from the core of steam flow in the IPC–LPC crossover tubes by sucking it to hollow adjustable vanes inside channels, and installation of cutoff guide vanes in the last-stage moisture-trapping chambers, which prevent secondary moisture from occurring in the flow path.*

(7) *Furnishing the turbine with modern means for monitoring linear and angular displacements and vibration state of turbine components with generating warning and emergency alarms.*

(8) *Replacement of a hydraulic governing system by a new automatic control system constructed on the basis of modern components and control algorithms.*

The turbine is equipped with a microprocessor electrohydraulic control and protection system (EHCPS) [2] in case of such retrofitting. The entire impulse part of the standard hydrodynamic control and protection system is dismantled, including the impeller pump, the unit of controllers (the control unit), the mechanical overspeed governor, and its slide valves. Only the following actuators are retained: the stop valve's automatic gate (SVAG), and the servomotors of the high- and low-pressure parts, which undergo minimal modification: electrical servomotor position sensors are installed instead of hydraulic feedbacks (cones), which are dismantled, and a power pump is installed instead of the pump group.

A functional diagram of the united electrohydraulic control and protection system for a T-100/110-12.8 turbine is shown in Fig. 2.

The retrofitted EHCPS consists of the following three main parts: a hydraulic part (CPS-HP), an electric part (CPS-EP), and electrohydraulic converters, which serve to convert the electric control signals produced by the CPS-EP into the hydraulic input signals for the CPS-HP.

The hydraulic part of the control and protection system includes a new power pump installed on the turbine shaft in the front bearing unit, the stop valve's automatic gate, servomotors of the high-pressure part's control valves, and servomotor of the adjustable vane used in the heating extractions from the turbine's low-pressure part.

The electrical part of the control and protection system, which is constructed on the basis of industrial controllers and actuators produced by Omron, includes an uninterruptible power supply cabinet (UPSC), a control cabinet (CC), an operator's workstation (OW), an engineering station (ES), and a set of sensors required for implementing the control and protection algorithms.

The electrical converters of the control and protection system are installed in the control and protection unit (CPU), which is constructed as a standalone assembly installed on the turbine maintenance platform near the front bearing and connected by hydraulic impulse lines to the CPS-HP actuators and by electrical control lines to the CC.

The UPSC takes its power supply from ac (220 V 50 Hz) and dc (220 V) sources and produces a 220-V ac power supply for the CC. The UPSC and CC are installed on the turbine maintenance platform; the CC touch-sensitive terminal is used as a local turbine control board during starting and adjustment operations.

The operator and engineering stations are installed at the group control board.

The control and protection unit (Fig. 3) comprises the following elements [2].

(i) A three-channel protection slide valve unit (PSVU) [3], which serves to control the supply of oil to the protection line in accordance with the 2 out of 3 logic. This unit comprises three independent protection slide valves united in one construction in such a way that, when in the cocked-up state, the PSVU connects the protection line with the line for supplying oil from the power pump, and if any pair of slide valves is set down, the protection line is connected to the drain and the pressure in it becomes equal to zero.

(ii) A solenoid valve unit (SVU), which converts electric protection signals that act for tripping the turbine into hydraulic signals (the pressure of oil in the impulse lines of slide valves used in the PSVU). Each solenoid valve controls its own protection slide valve. The solenoid valves serve as electrohydraulic converters of the turbine protection system.

(iii) Two control slide valve units (CSVUs), each made as a rotary throttle slide valve controlled by an electric motor from the controllers used in the CPS-EP. These units serve as electrohydraulic converters in the turbine control system.[1]

(iv) An intermediate protection slide valve (IPSV) unit, which serves to control the governing system's servomotors from the protection system (an additional hydraulic protection channel).

[1] Figure 3 shows the standard CPU equipped with three control slide valve units, which is used for PT turbines; T-type turbines are equipped with two CPUs.

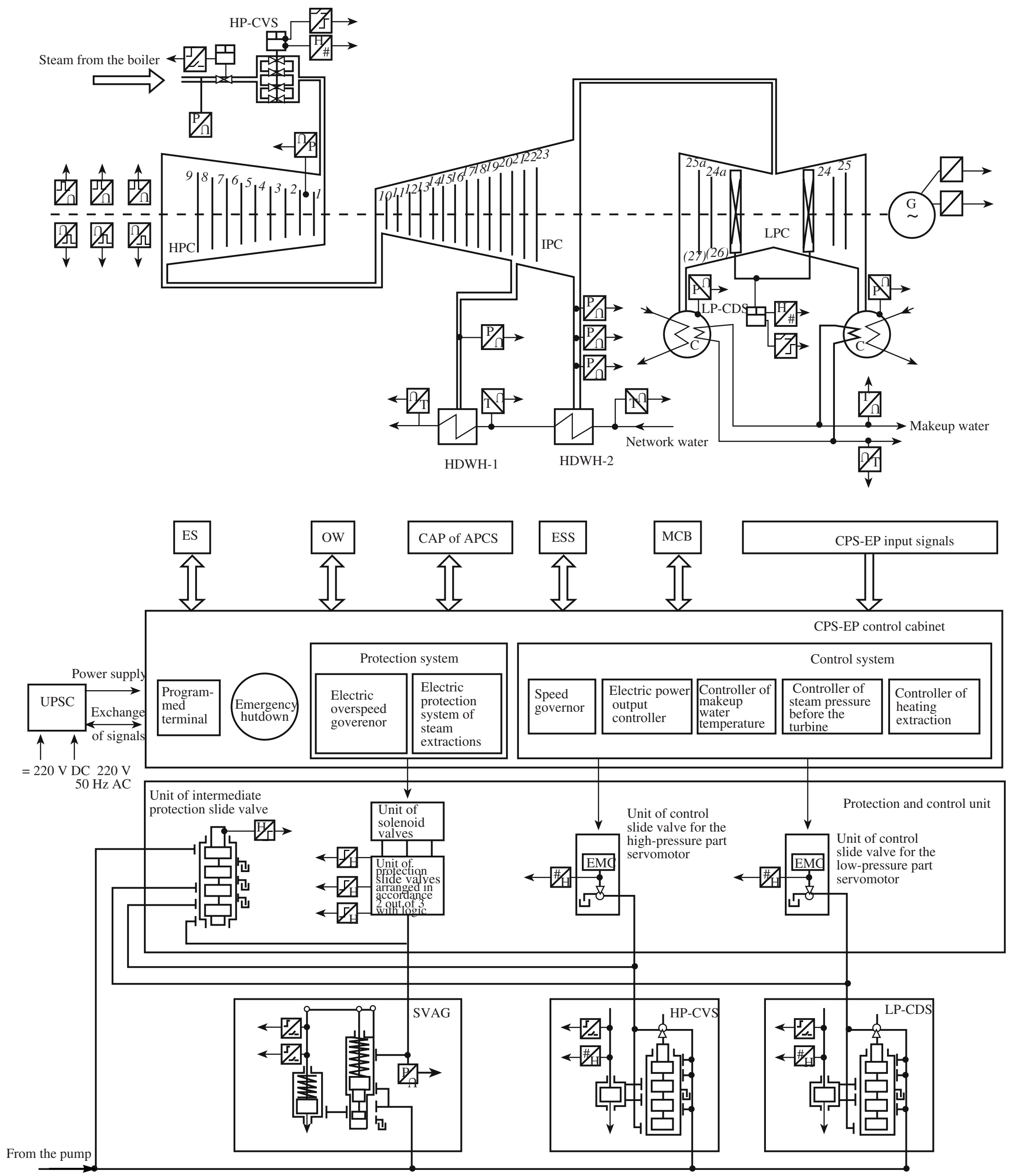

Fig. 2. United functional diagram of the electrohydraulic control and protection system of the T-100/110-12.8 turbine. HP-CVS is the servomotor of high-pressure control valves, LP-CDS is the servomotor of low-pressure control diaphragm, HDWH-1 and HDWH-2 are the first and second delivery-water heaters, C is the condenser, G is the generator, CAP of APCS is the computerized automation platform of the automated process control system, and EMC is the electromechanical converter.

The control system comprises the following controllers:

(i) a speed governor with a droop of 4–5% and dead band of 0.02–0.06%;

(ii) a controller for steam pressure upstream of the turbine (for operation in the boiler–turbine unit configuration);

(iii) a controller of electric power output equipped with a frequency corrector, which maintains the specified power output with accuracy of 0.5 MW;

(iv) a controller for maintaining the minimal pressure of steam upstream of the turbine;

(v) a controller of heating steam extraction, which maintains steam pressure in the chamber of the upper or

lower heating extraction with accuracy of 0.01 MPa or the temperature of delivery water at the outlet from the delivery-water heating installation (or its heating) with accuracy of 0.5°C; and

(vi) a controller for the makeup water temperature, which maintains it with accuracy of 0.5°C.

The control system also includes protection (limiting) controllers, which serve to ensure safe operation of the turbine in the entire range of operating conditions and prevent erroneous actions of the operating personnel (controllers for the maximal levels of pressure after the turbine control stage, in the heating extraction, in the condenser, and others).

The CPS-EP also incorporates a three-channel overspeed protection constructed in the form of an electrical overspeed governor, which implements the 2 out of 3 logic jointly with the PSVU, a solution that makes it possible to exclude false operation of one protection channel and carry out individual tests of each channel along its entire path including the setdown of the corresponding slide valve on the running turbine without stopping it. The algorithm of the electric overspeed governor analyses a combination of the rotation frequency and acceleration, an approach using which the setpoint at which the governor comes into action in response to malfunction in the control system can be reduced considerably (by 4–5%).

The CPS-EP also incorporates a three-channel electric system for protection from excessive pressure in the chamber of controlled heating extraction, which is constructed similarly to the electric overspeed governor and allows individual channels of the protection to be tested on the running turbine. With the electric extraction protection system incorporated in the CPS-EP, it becomes possible to dismantle large-diameter safety valves. As a result, smaller inleakages of air are obtained and the operation becomes easier.

The unit of solenoid valves also receives signals for tripping the turbine from the technological and electric protections of the turbine generator, as well as commands for remote shutdown of the turbine by the operator.

The CPS-EP also serves for the following in all modes of operation:

(i) monitoring the sensors, communication lines with field equipment, and power supply circuits;

(ii) bumpless connection and disconnection of controllers;

(iii) carrying out the necessary tests (e.g., speeding up, increasing the pressure in the controlled extractions, and others) and determining various characteristics;

(iv) displaying, recording, and archiving messages about changes in operating conditions and deviations from normal operation of the turbine (including emergency ones); and

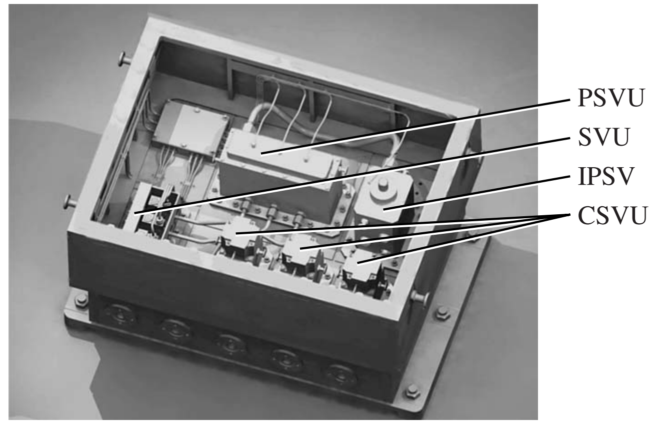

Fig. 3. Protection and control unit.

(v) communication with the automatic process control system of the combined-cycle plant.

The following projects are proposed as additional options.

Retrofitting the support-thrust bearing or installing a new support-thrust bearing. Layered thrust segments are installed, which have high bearing capacity due to reduced thermal and stress strains of segments that are obtained by applying forced oil cooling of the most heated part of these segments and using a steel bearing pedestal. Tangential removal of oil from the bushing is organized.

Improving the oil tightness of bearing shells. All rolled oil rings are replaced by flanged ones. The sealing element (oil trap) is made of fluoroplastic and is furnished with inclined sealing tabs.

Installing tight control diaphragms in the low-pressure part allows steam leaks to the turbine exhaust hoods during operation with full heat load to be reduced to 5–7 t/h.

Shifting the turbine to operate in the backpressure mode using a low-pressure spacing rotor.

Organizing an additional steam extraction with a flowrate of 70 t/h and pressure of 1.3 MPa from the HPC–IPC crossover pipes with installing a unit of protection and control valves.

Retrofitting the turbine thermal displacement system by installing sliding surfaces made of thick hardened plates between the bodies of supports and foundation frames. Measures to compensate for the consequences of foundation settlements can be taken if necessary.

Installing fully variable steam shields immediately after the outlet edges of last-stage rotor blades for cooling them during operation in steamless modes and protecting them from erosion.

Partial retrofitting of the thermal circuit.

The selected options are fully or partially included in the overall scope of retrofitting on an agreement reached upon direct technical discussions between the customer and UTZ. The procedure of discussing and approving technical specifications for retrofitting is a mandatory stage of work.

In addition, programs for retrofitting T-50/60-12.8, PT-50/60-12.8/7, and R-38-12.8/32 turbines have been developed at UTZ. If necessary, the programs for retrofitting PT-135/115-12.8, T-185/210-12.8, and T-250/300-23.5 turbines can be continued.

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